


SMALL HYDROELECTRIC POWER DEVELOPMENT
IN CHINA

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SMALL HYDROELECTRIC POWER DEVELOPMENT IN CHINA

Francis R. Skidmore*

Abstract

This report summarizes the status of small scale hydroelectric power development in China. It includes an overview of electric power development in China as well as the status of small hydropower development and technology. Information is derived from open literature sources.

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1. Overview of the Chinese Energy Situation

China's development of small hydroelectric power projects has been dramatic. It is best understood in the context of China's overall energy situation. Although the nation is self-reliant in energy supplies, its annual consumption is only 26 quads (1 quad = 10^{15} BTU), or one-third that of the United States (Fig. 1). With a population of approximately 970 million, this rate of consumption on a per-capita basis is one-fourteenth that of the United States. This energy situation is a serious constraint to China's economic development, and, conversely, energy development figures prominently in China's modernization plans.

Electric power production is viewed as one key to modernization of the country and an important part of the solution to energy shortages. Currently, electric power capacity is about 50,000 MW, which represents an impressive growth from the 1800 MW capacity existing in 1949, but is still only one-twelfth that of the United States.¹ In addition, a national transmission grid has not developed, as the geography of China tends to compartmentalize the nation into separate isolated regions. Approximately 21,000 MW of capacity is controlled from four grid control centers (Fig. 2):²

Northeast System—Kirin, Harbin - 7000 MW capacity

Peking System—Peking, Tangshan, Tientsin - 4000 MW, 5% hydro

East Coast System—Shanghai, Nanking - 7000 MW, 20% hydro

Northwest System—Liuchia, Sian - 3000 MW, 50% hydro

The remaining 30,000 MW is not connected to a major grid. This 30,000 MW capacity tends to be distributed on provincial or smaller county grids that are independently controlled and not interconnected.

Energy development is particularly a problem for the rural communities. Approximately 80% of the population is rural, but only 30% of China's energy is consumed there.³ Rural per-capita electrical consumption is, perhaps, 40 kW-hr annually. The rugged Chinese terrain and a poorly developed transportation net isolates the rural communities and makes development difficult.

Given this energy situation, particularly as it has existed for the past 30 years, the large hydroelectric potential in China naturally received considerable attention. Total hydroelectric potential is estimated to be as much as 580,000 MW,* situated on 1600 rivers and the existing canals.⁴ The Chinese were determined to promote self-reliance in their drive for modernization and followed a policy of "walking on two legs." With regard to hydroelectric development, this policy meant parallel development of small, low capital hydro projects at the rural commune level together with large, capital intensive central power projects.⁵

Initiated in the 1950's, both legs of hydro-development have shown progress, but the small scale development of rural hydropower has been spectacular. Currently, the hydroelectric capacity in China is estimated** to be over 16,000 MW,⁶ with greater than 60% of the capacity in 53 known stations which each exceed 30 MW.⁷ Small and medium plants of less than 30 MW capacity, however, exceeded 90,000 in number as of the end of 1979,⁸ with as much as 60% of the units less than 500 KW in size.⁹ The number of small projects constructed in 1979 exceeded those in 1978¹⁰ and indications are that the program will continue to expand in future years.

With this understanding of the general context for small hydroelectric development in China, the remainder of this paper will examine historical development principles, the existing system, and current technology.

2. Historical Development of Small Hydroelectric Power

The small hydroelectric program was initiated in 1958 as part of a massive water conservation effort during the Great Leap forward, when as many as 100 million people worked to improve the irrigation system in rural China. Over 300 MW of small hydro went on line in 1958-1959 before the program collapsed. Resurrected in the mid 1960's, the program picked up momentum in 1969 after the end of the Cultural Revolution.¹¹

* Including Taiwan

**With ongoing construction, total hydropower capacity will likely exceed 18,000 MW in 1980.

General development guidelines were based upon local self-reliance. With the exception of assistance in power machinery selection, almost all resources came from local (county or lower) sources. Maximum thrift and simplicity were emphasized, coupled with construction speed. Funds came from local agriculture and light industry, with central funding only for design assistance, power equipment selection, and operator training. Dams tended to be rock or earth filled.¹² Even turbine/generator manufacture was decentralized to a regional basis. It was a natural consequence that projects were interconnected on county grids, but larger grids rarely developed.

As development progressed, staircase development of the rivers frequently occurred. In the staircase concept, water regulation reservoirs are built at the highest reaches of the river, with power stations placed at lower levels in the populated area.¹³ The small hydro projects then operate as a system. It is important to note, however, that the power stations are usually constructed as part of an overall rural water development project. Power generation is often secondary to other multi-use considerations - especially irrigation. Thus the power generation is intermittent or supplementary and load factors can be quite low.

With increasing emphasis to this highly visible rural modernization program, small hydro capacity had increased to approximately 2500 MW in 1975¹⁴ and 6330 MW by the end of 1979.¹⁵

3. Current Status of Small Hydroelectric Development

In the United States, small-scale hydro is defined as less than 15 MW and low head is under 66 feet. In China, projects under 12 MW or individual turbines less than 6 MW are considered small. Units under 500 MW are "for agricultural purposes," whereas units ranging from less than a kilowatt to 200 kilowatts are micro or mini sets.¹⁶ Stations with capacities between 12 MW and 30 MW are regarded as medium size.

Total electrical generation capacity in China exceeds 50,000 MW, of which approximately one-third or over 16,000 MW is hydroelectric. Total generation is estimated to have been approximately 275 billion kW-hr in 1979 of which only 20% is hydroelectric,¹⁷ reflecting lower load factors from intermittent water supplies. As of 1977, hydroelectric capacity included 6 projects exceeding 500 MW, 13 in the 300 MW to 500 MW range,¹⁸ and 34 between 30 MW and 300 MW.¹⁹ As of 1979, 90,000 units of less than 30 MW capacity were in existence. The largest hydroelectric project is Liuchiachia in Kansu Province at 1225 MW,²⁰ but the Gezhoubu "low-head" project on the Yangtze River (88 ft head) will equal 2400 MW when completed.²¹

There is confusion in the literature between the statistics relating to medium (12 MW to 30 MW) and small (less than 12 MW). Sources tend to lump small and medium together under the general heading "small." Consequently, the number of medium plants is uncertain.

Small (including medium) hydro capacity is currently 6330 MW, possibly generating 12 billion⁺ kwhr annually.²² This power production represents 20% of all hydroelectricity, 30% of all rural electricity,²³ and 40% of all agricultural electric power consumption,²⁴ but only 4% of total electrical generation.

Small projects are usually designed to operate at least 2000 hours per year,²⁵ but tend to have a low load factor, perhaps 25% or less, as a weighted annual average. Rough calculations show large hydro may average closer to 50% and thermal plants approximately 70%.

Small hydropower is concentrated in southern China (Figure 3) but 1500 counties out of 2200 total have their own systems.²⁶ Approximately 50% of the counties in China have a potential hydropower capacity of 10 MW or more.²⁷ At present, 600 counties derive the majority of their agricultural and industrial power from small hydro power and 113 exceed 10 MW in capacity.²⁸ Largely due to small hydro, over 86% of all the communes in China are electrified.²⁹

As has been mentioned, small hydro projects are local in nature and linked to small county grids. Since the plants provide an intermittent supply, other non-hydro county plants are normally in the grid to provide reliability. Transmission voltages in China are 10 kV, 35 kV, 110 kV, 145 kV, and 220 kV, with at least one 330 kV line in existence.³⁰ Three 500 kV lines are being planned.³¹ Energy from small hydro projects is normally not transmitted at a voltage above 110 kV.³²

Control of the hydroelectric projects appears to be based upon size. The large projects are controlled by the Ministry of Water Conservancy and Electric Power in Peking. Small projects are controlled at local levels. The system in Guangxi Province provides a guide on how this is done. In Guangxi, medium projects (exceeding 12 MW) are usually run by provincial prefectures, 1 MW to 12 MW are run by counties, 100 kW to 1000 kW by communes, and those below 100 kW by brigades.³³

The uses for power generated by small hydro projects are varied. First, small hydro is a rural development tool that often serves as the first step toward modernization. Given that, emphasis has been to provide power for small local industries, such as fertilizer or cement, a few light bulbs for the homes, and, most importantly, power for agricultural purposes. Power frequently comes in the form of mechanical belt driven equipment directly linked to the turbines as well as from electricity. Irrigation pumping, timber sawing, husking, milling, threshing, and fodder crushing are typical employments for a small hydro power source.³⁴

Some impressive small hydro systems are reported which have been very effective in rural modernization. Typical of such systems is one in Yangshan County of Guangdong, which links 170 stations to provide a capacity of 12,000 kilowatts and 43 million kW-hr of electricity in 1978. The resulting low priced electricity enabled the county to build and power a 10,000 ton per year nitrogenous fertilizer plant, a 10,000 ton per year phosphate fertilizer plant, a 40,000 ton per year cement plant and a small 55 ton per year coal pit. The hydro system had enabled a five-fold increase in industrial output for the county.³⁵

Overall, small hydro capacity is expanding, with construction goals of 1000 to 1200 MW per year for the years 1980 to 1982.³⁶ The Chinese Government appears now to vigorously promote small hydro stations through low interest loans and privileged electricity rates. Ultimately, it is hoped that 1100 counties will each exceed 10 MW capacity in small hydro development.³⁷ The subject is not without controversy, however. There is evidence of small hydro advocates exhorting the people to achieve the basic good of this type development, and not to be dissuaded by large power advocates who claim that small hydro is a waste of effort.³⁸

4. The Technology

The Chinese produce the vast majority of their own turbines, including large ones. The general impression is that Chinese turbine designs for small hydro are approximately the same as American designs. Fixed and movable blade propeller turbines (axial flow) are used for smaller heads. Francis turbines (mixed flow) and impulse turbines are used for the higher head ranges. Mechanical reliability is high.

One source has provided a more detailed basis for analysis, however, and is the primary reference for the remainder of this section.³⁹

Small turbines were originally designed by the Chinese for simplicity and reliability, but in recent years have also been refined for efficiency. In 1972, standardization of equipment started, and since then a considerable national effort at unified design and quality control has occurred. Standardization was achieved for turbine generating sets operating in head ranges of 2.5 to 400 meters and 12-12000 kW. These standard turbines are basic fixed blade and Kaplan, mixed flow (Francis) and impulse designs.* Examples are in Table 1.^{40,41}

*Manufacturer's information, including specifications and turbine schematics are available in References 40 and 41.

More recently, tubular turbines have been developed for very low heads and large flow rates. These tube turbines are still in research and development. In addition, a bulb-type tubular turbine with 10 MW capacity and a small bulb type experimental turbine rated at 500 kW for tidal power are currently being constructed and tested.

There is information that a variety of designs for very small turbines have been developed, including one with capacity of just 200 watts. Two designs for sets of 5 kW capacity are now offered for U.S. import. One design is particularly unusual. The WZXJ-5/1800 set contains an upright axial flow reaction turbine with inclined water jets. It operates at 131 feet head and 0.8 CFS, with a runner of 6 inch diameter and water jets of 1.6 inch diameter. Larger turbines of the same design range up to 160 kW capacity.⁴² Two 5 kW turbine-generator sets, one of which is of the type just described, have been purchased for use by the State of California Department of Water Resources.

Synchronous generators are used with small scale hydro projects because of the isolated nature of the county grids. Their design appears similar to U.S. designs,⁴³ although improved voltage regulation features have been noted by Tseng.

It is reported by Tseng that approximately 36 qualified small turbine factories exist in China. Production exceeds 1000 MW per year, and factories are not producing at capacity. Another source reports that as many as one hundred factories in China produce power generation equipment.⁴⁴ In fact, production was decentralized from the start and the existence of a large support infra-structure that accompanies the factory itself (hospitals, homes, etc.), inhibits specialization or centralization of manufacturing capability.

Technology transfer is accomplished semiannually at national conferences which engineers and administrators attend. Government emphasis on the conferences insures good attendance and technical exchanges.

To generalize, the Chinese technology appears to possess many strengths in the mechanical attributes of turbines and control systems. Simplicity and reliability is apparently stressed. Particularly from the operating experience of 90,000 units, the Chinese are reported to have developed sophisticated controls to maximize efficiency and minimize problems, such as cavitation, over a wide range of conditions. The equipment also appears cost competitive with American sets. Weaknesses tend to be in the electrical equipment effecting grid connection.⁴⁵

In summary, Chinese small turbine technology is basic but sound, with designs which benefit from extensive experience. Electrical connections and transmission are sometimes less advanced.

5. Conclusions

The small hydroelectric development in China is extensive, with more than 90,000 units, but represents a very small resource in terms of total electricity generation (or little as 4%). In the rural areas, however, small hydro is an important tool for modernization and represents a substantial percentage (30%) of the electricity. Its characteristics - simplicity, reliability, and low cost are ideal for isolated underdeveloped areas.

Good turbine design is largely an empirical science. The Chinese experience in developing technology for a large variety of operating conditions has provided an empirical basis for good designs. Their small turbines and accompanying control mechanisms thus appear to be competitive in the American market. It is not obvious that other technology, especially on the electrical side, has advantages for the American market.

It appears that the Chinese emphasis on small hydroelectric development, in parallel with large central development, will continue in the future. Technical development, especially in the small standardized turbine area, should continue as well.

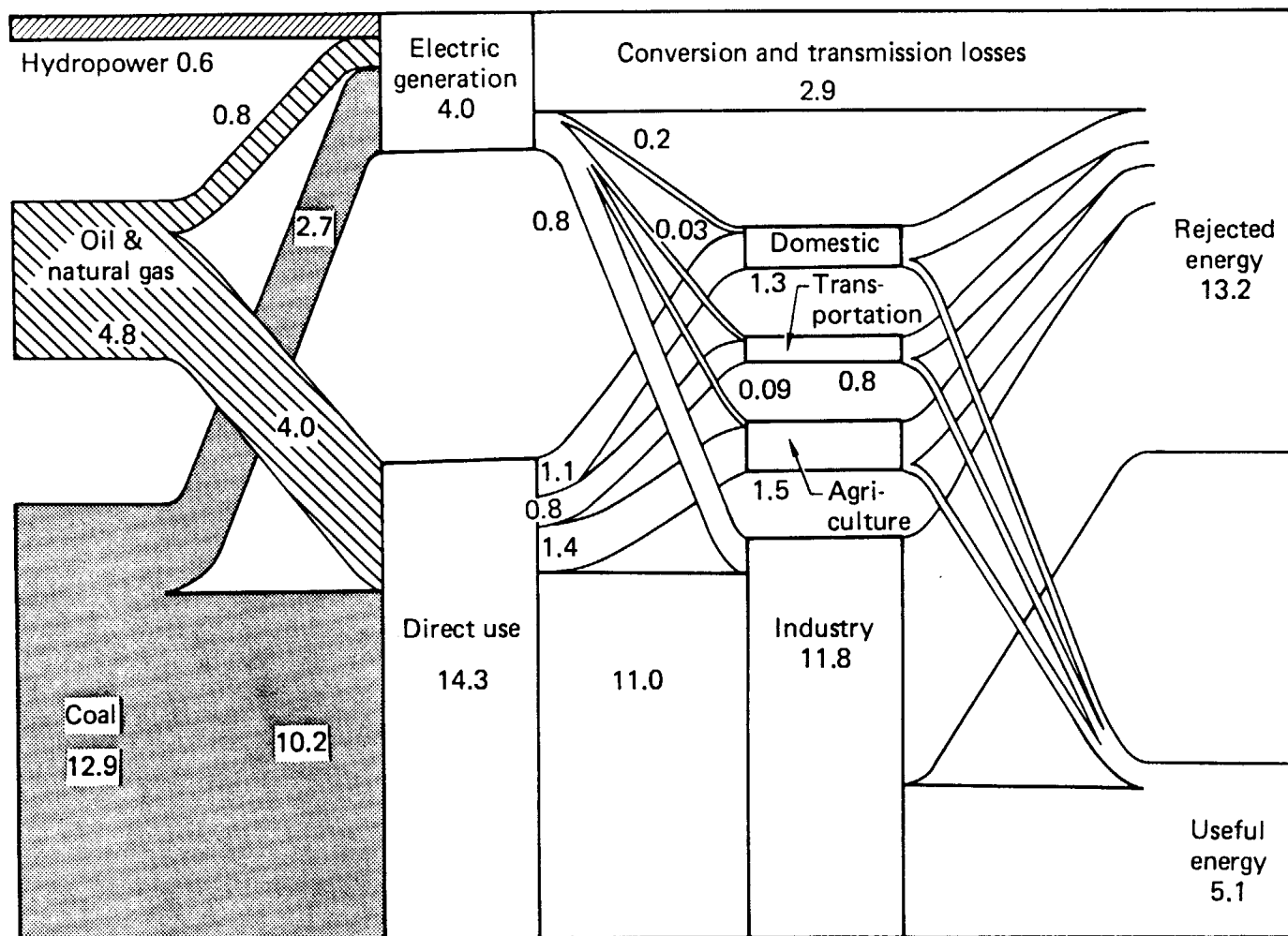
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Total commercial energy consumption = 18.3 quads (1 quad = 1×10^{15} btu.)
 Rural energy consumption (not included) = 7.8 quads.

Figure 1. Energy distribution patterns in China for 1979

Source: A. L. Austin, A Summary on Geothermal Energy Development in China

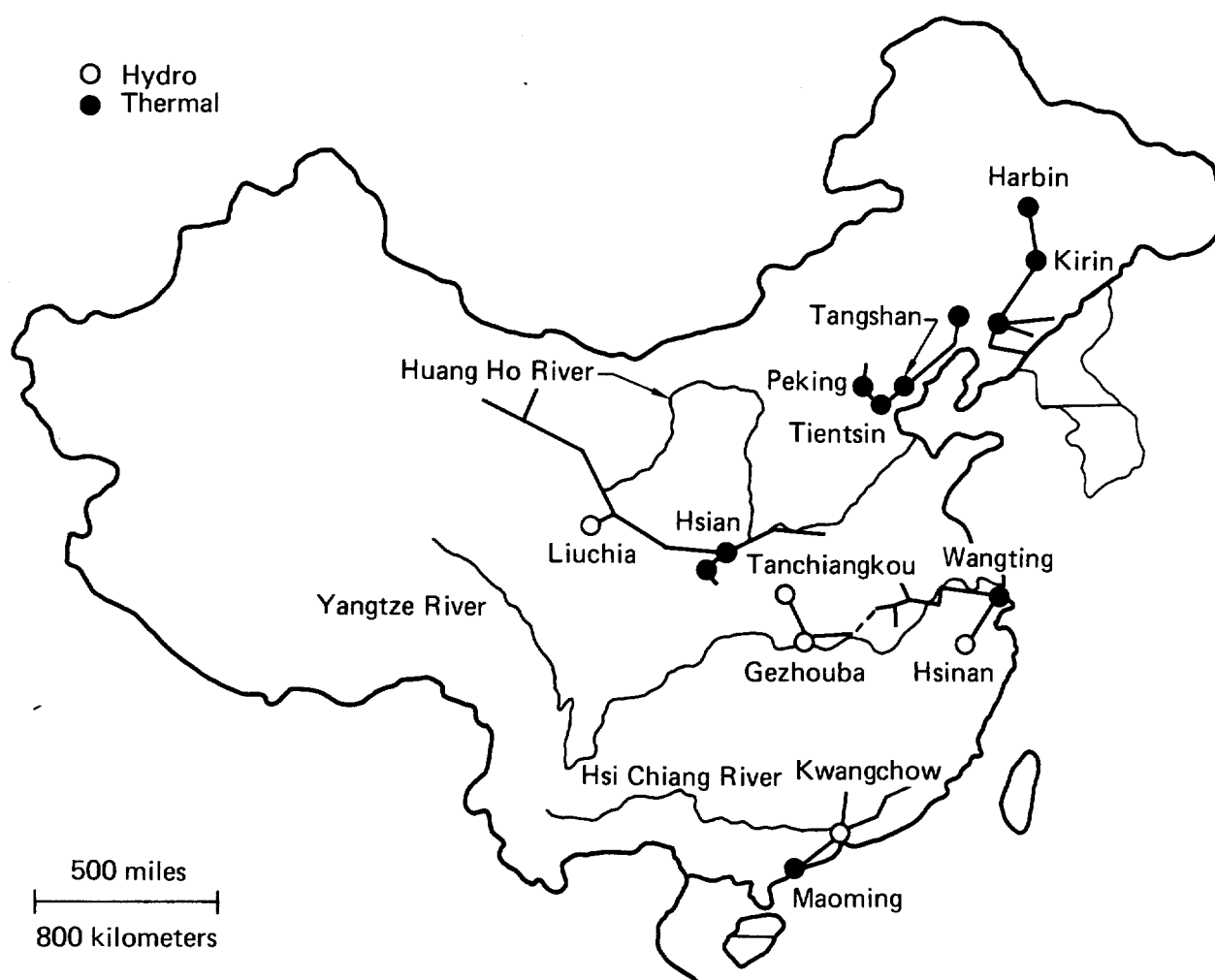


Figure 2. China grid system

Reference: Shepherd, "Electricity Development in China"

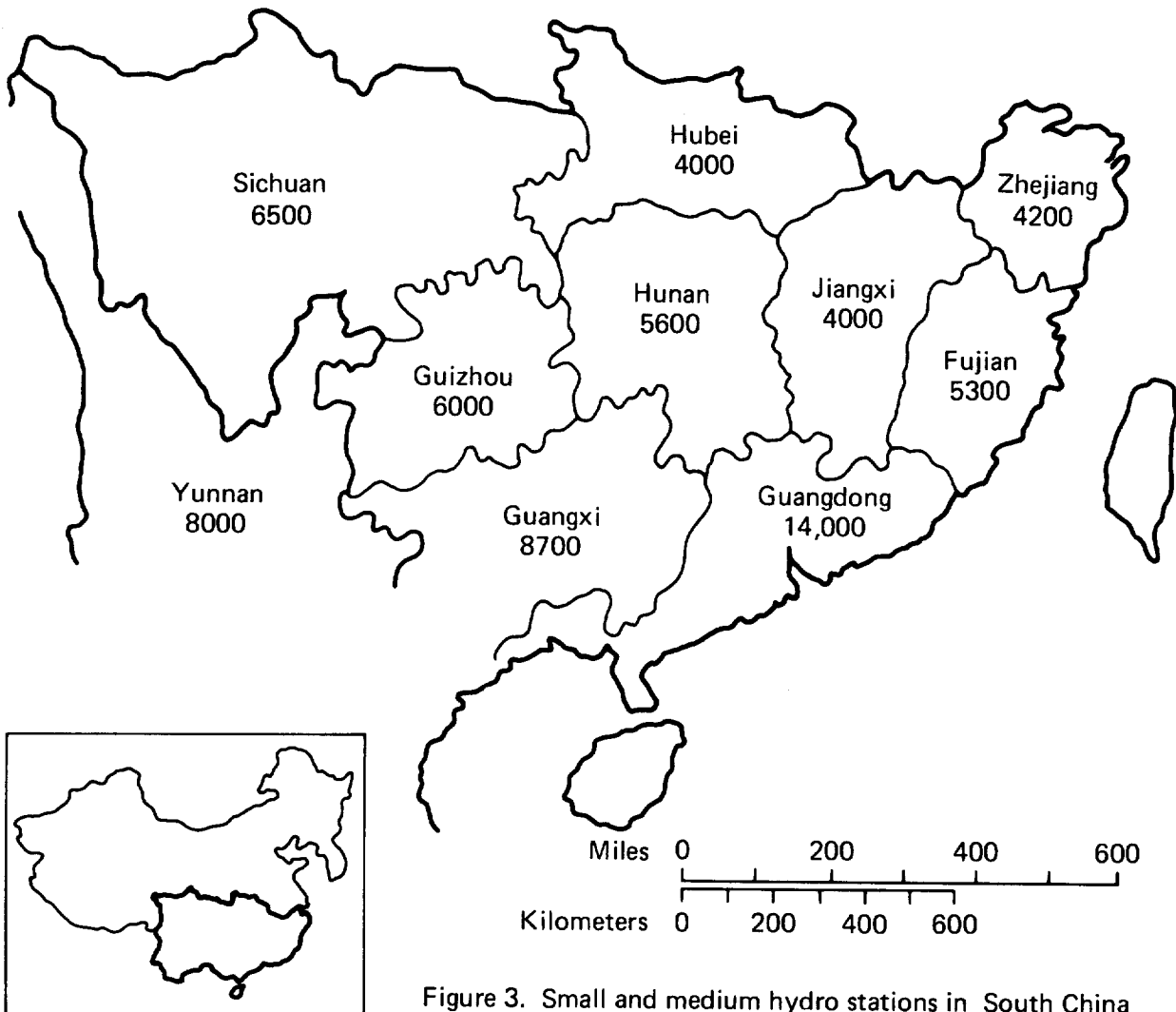


Figure 3. Small and medium hydro stations in South China

Reference: From Smil, "Intermediate Energy Technology in China" (updated with recent estimates where available)

TABLE 1
SPECIFICATIONS OF WATER TURBINE GENERATOR SETS 12-500 KW

Item №	Turbine				Generator				
	Type	Model	Head (M)	Flow (m³/ sec)	Capacity of Generator (kW)	Speed (rpm)		Voltage (v)	
						50Hz	60Hz	50Hz	60Hz
1	Axial-flow reaction type	ZD760-LM-60	2~6	0.80~1.80	18, 30, 40, 55, 75	1000	1200	400	460
2		ZD760-LM-80	2~6	1.40~3.50	30, 40, 55	1000	1200	400	460
					75, 100, 125	750	900	400	460
3		GD560-WZ-60	8~14	0.90~2.20	40, 55, 75, 100, 125, 160, 200	750	720 (900)	400	460
4	Mixed-flow reaction type	HL210-WG-20	6~15	0.12~0.19	12, 18	1000	1200	400	460
5		HL310-WG-30	6~18	0.32~0.53	18, 30, 40, 55	1000	1200	400	460
6		HL260-WJ-35	10~25	0.50~0.80	55, 75	750	900	400	460
					100, 125	1000	1200	400	460
7		HL260-WJ-42	8~25	0.65~1.15	75, 100, 125, 160	750	900	400	460
					200	1000	1200	400	460
8		HL110-WJ-42	30~80	0.36~0.59	100, 125	750	900	400	460
					160, 200, 250, 320	1000	1200	400	460
9		HL240-WJ-50	15~40	1.20~2.00	125, 160, 200	600	600	400	460
					250, 320, (400)	750	720 (6300)	400 (6300)	460 (6300)
					500	1000	900	6300	6300
10		HL220-WJ-50	25~59	1.50~1.80	320, (400)	750	720 (6300)	400 (6300)	460 (6300)
					500	1000	900	6300	6300
11		HL110-WJ-50	35~80	0.56~0.85	200, 250, 320	750	900	400	460
					400, (500)	1000	1200	400 (6300)	460 (6300)
12		HL110-WJ-60	30~70	0.70~1.10	160, 200	600	600	400	460
					250, 320, (400)	750	720 (6300)	400 (6300)	460 (6300)
13		HL240-WJ-71	23~32	2.90	500	500	514	6300	6300
14	Impulse type	CJ-W-55/1×58	100~260	0.12~0.19	75, 100, 125, 160	750	720	400	460
200, 250, 320, 400					1000	900	400	460	
15		CJ-W-65/1×72	100~260	0.18~0.29	125, 160	600	600	400	460
					200, 250, 320, (400)	750	720 (6300)	400 (6300)	460 (6300)
					500	1000	900	6300	6300
16		CJ-W-92/1×11	138~145	0.50	500	500	514	6300	6300

Source: Oriental Engineering & Supply Company